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PROJECT SPOTLIGHT

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Using Nature's Plumbing to Restore Aquatic Ecosystems: The City of Seattle's Natural Drainage System

James N. Levitt and Lydia K. Bergen
Program on Conservation Innovation at the Harvard Forest, Harvard University

Laura Lombardo Szpir
NCSU Water Quality Group

Salmon, steelhead trout and their cousins that make the epic journey from freshwater streams to the ocean and back again, are charismatic symbols of America's Pacific Northwest. These fish, known by the scientific community as anadromous species, are iconic reminders of the region's spectacular natural abundance. Salmon and other natural aquatic communities in and around Seattle's Puget Sound are, however, in trouble. After years of public debate, several species of Pacific salmon now appear on the federal threatened and endangered species lists. In part in response to the listing, urban, suburban and rural communities in the Puget Sound watershed have engaged in various efforts aimed at bringing back healthy salmon populations, including stream and estuary restoration projects and community education programs. These restoration and education programs alone, unfortunately, have not gone far enough.

In contrast to salmon and the streams in which they live, the region's stormwater management systems are decidedly uncharismatic. Historically, local voters generally have not given much thought to stormwater management, unless they or their neighbors have flooded basements after a heavy rainfall.

Despite the prosaic nature of stormwater drainage systems, Denise Andrews, an employee of Seattle Public Utilities (SPU), recognized an opportunity to innovate at the intersection of stormwater management and salmon habitat restoration.

When the city announced in 1998 that it would fund a series of small, innovative projects as a way to celebrate the coming Millennium, Andrews and other stormwater planners with SPU proposed a scheme for installing natural drainage systems in northwest Seattle neighborhoods that had inadequate stormwater management systems. Such natural drainage systems utilize soil and plants—nature's drainpipes—to substantially decrease surface runoff from impervious surfaces such as city streets, thereby encouraging the absorption of rainwater into the natural subsurface hydrologic systems, changing stream flow conditions and reducing pollutant loads in aquatic ecosystems. In effect, Andrews and her colleagues (see Figure 1) had envisioned a way to integrate an existing gray infrastructure with a novel green infrastructure in a major metropolitan area. The city approved an initial planning grant, thus launching the effort, now known as the SPU Natural Drainage Systems (NDS) program.

Figure 1. NDS Team (left to right): Miranda Maupin, Jim Johnson, Denise Andrews, Darla Inglis. Tracy Tackett not shown.

With a team of civil engineers, landscape architects, fire and police department representatives, Seattle Public Utilities managers and local elected officials, Andrews set out to demonstrate that low-impact development (LID) strategies for stormwater management could be both technically effective in improving aquatic ecosystem health, and economically efficient at getting the job done. By 2004, the team has succeeded well beyond their expectations, developing five natural drainage projects, including the recently completed Broadview Green Grid, a project covering 15 city blocks in northwest Seattle's Piper's Creek watershed.[1]

For their efforts, the NDS team has received wide recognition. Visitors from as far away as New Zealand have come to inspect and consider replication of the novel and measurably effective stormwater system design. The team has also successfully engaged in a rigorous competitive process to win one of five 2004 Innovations in American Government Awards presented by the Ash Institute for Democratic Governance and Innovation at Harvard University's Kennedy School of Government.

The Stormwater Management Challenge

Stormwater management is a challenge to existing and emerging urban, suburban and rural settlements across the United States and around the world. In conventional stormwater

EDITOR'S NOTE

In past issues of *NWQEP NOTES*, we featured innovative stormwater management programs of cities such as Philadelphia, PA and Greensboro, NC. In this issue, we highlight the City of Seattle's award-winning *Natural Drainage Systems* program, established with the ultimate goal of helping reduce impacts of development on Pacific salmon and other important aquatic communities of Puget Sound. The practices employed include *Street Edge Alternative* (SEA Street) design, in which existing streets are reconstructed to be narrower and drain to beautifully landscaped vegetated swales, and *Cascades*, a stair-stepped system of swales and pools, which replace existing concrete drainage ditches. Monitoring of pilot projects indicates that both of these stormwater control strategies are highly successful at reducing runoff volume, peak flow, and increasing infiltration. They have also shown to be cost effective and desirable by the public. Based on these positive results, Seattle is expanding its application of *Natural Drainage Systems* into other areas of the City, including a high-density redevelopment project, which will provide a wonderful opportunity for showcasing the implementation of low impact development in an urban retrofit setting.

As always, please feel free to contact me regarding your ideas, suggestions, and possible contributions to this newsletter.

Laura Lombardo Szpir

Laura Lombardo Szpir
Editor, *NWQEP NOTES*
Water Quality Extension Associate
NCSU Water Quality Group
Campus Box 7637, NCSU
Raleigh, NC 27695-7637
Tel: 919-515-3723, Fax: 919-515-7448
Email: notes_editor@ncsu.edu

systems engineered in the twentieth century, a network of impervious troughs, tanks and pipes fit together to literally drain an area. Such conventional stormwater systems send irregular, high velocity flows of storm runoff into natural bodies of water, including streams, ponds, lakes and bays. Such flows result in unnatural erosion and the subsequent deposition of sediment. These factors alone can seriously disrupt habitat for aquatic species. In addition, in conventional systems the runoff from storms washes pollutants such as pesticides, motor oil, and bacteria from animal waste off of streets and other impervious surfaces into the piped system. By sending such contaminants down the drain, and then swiftly into local streams, lakes and estuaries, traditional stormwater management systems can further harm local freshwater and marine ecosystems.

A More Efficient, Effective Alternative

The natural drainage systems (NDS) approach to these problems is simple in concept: restore and utilize the environment to do the work it was intended to do. Generally, the NDS approach does so by: 1) increasing along the edges of city streets the amount of soil and plants in an interlinked network of vegetated swales and cascades; 2) reducing the area of impervious surfaces on the street itself by adopting new, multi-functional street designs; and 3) using these landscape features to allow stormwater to be absorbed into the ground, rather than sending polluted water, at unnaturally high velocities, to rush into local streams, lakes, and bays.

The NDS techniques employed in various SPU pilot projects are described further below.

SEA Street:

Street Edge Alternative (SEA) street design consists of a series of shallow, generally flat-bottomed, heavily vegetated swales placed along a gently curving street (see Figures 2 through 5). This type of system is considered to be a *source control* strategy because it manages the stormwater runoff from the immediate surrounding area. The system infiltrates and detains stormwater to maximize the water quality and flow control benefits. The bottom widths of the swales will vary depending on the amount of room available, but at least a 2-foot bottom width is recommended and not more that 4-feet in depth. Side-slopes are graded at 3:1 along the road, but may be slightly steeper on the property side. Generally, these systems attempt to treat all runoff in the immediate basin from the 6-month, 24-hr storm by filtering the stormwater through vegetation and infiltrating the water through the soil media. The stormwater flow control goals are to maximize retention, infiltrating at a minimum all flow generated by a ½-inch storm event, and maximize detention, ideally detaining the developed 1-2 year storm event for the adjacent drainage area to pre-developed forested conditions.

Figure 2: Street before conversion to Street Edge Alternative (SEA) design.

Figure 3: Street after conversion to SEA design.

Cascade:

A cascade refers to a stair-stepped system of wide, flat-bottomed, heavily vegetated swales or pools (see Figures 6 and 7). The system treats an area of runoff larger than just its street and is considered more of an *end-of-pipe* strategy. The system slows stormwater flows, allowing maximum opportunity for deposition of solids, infiltration of runoff, and bioremediation of chemical pollutants. The primary objective of this type of system is to reduce the peak flows to the receiving downstream creek system and achieve some level of water quality treatment. Generally, these systems attempt to detain the flows generated by the full drainage basin to reduce the 2-yr, 24-hr storm to pre-developed forested conditions or provide maximum volume detention for this event. In addition, conveyance of the 25-yr, 24-hr storm through the full length of the project must be achieved. Water quality goals for these systems are generally undefined, but whatever is achievable is characterized as an added benefit.

Soil Mixes:

There are two types of soils typically used within the NDS – bioretention soil and engineered soil. Swales should be overexcavated and the native soil replaced with the appropriate amended soil mix. Swale soil depth should be a minimum of 1 foot, with a 2-foot preferred depth. When using the engineered soil, a 2-foot depth is often necessary to provide sufficient storage volume to hold the water while it infiltrates into the native soil. Both of these mixes should have approximately 20-30% available void volume and between 8 and 12% organic content.

Figure 4. An aerial view of SEA street design showing narrow, curvilinear streets with sidewalks and street-edge gardens.

The *bioretention* soil has infiltration rates of 0.5 to 1 inch per hour at 85% compaction and is most typically used on the SEA street systems, except in areas where higher rates are needed, and along the banks of the Cascade systems. Native soil on site can be amended with 30% compost if it is an outwash or weathered till material, otherwise imported material can be used.

The *engineered* soil has infiltration rates between 1.5 to 2 inches per hour at 85% compaction and is most typically used in the Cascade systems. It is generally composed of 50-60% sandy material, 25-30% compost, and 15-20% sandy loam topsoil.

Figure 5. Swale as part of SEA street design.

Project Results

Initial tests of the pilot projects to date have been so successful that SPU has made a commitment to utilize NDS as its primary stormwater management approach in all areas that drain directly to creeks. Based on early results, the city is recognizing that three types of benefits are most notable: environmental benefits, cost effectiveness, and public appeal.

Environmental Benefits

Studies of SPU's pilot projects reveal that they are extremely successful at capturing water flow and reintroducing it to the natural groundwater system. SPU constructed two drainage projects in the northwestern part of the city to decrease stormwater quantities discharged to Piper's Creek, with the goal of reducing channel erosion and water pollutant loadings to the stream. The first project, the Viewlands Cascade Drainage System, replaced a narrow, partially concreted ditch with a wide series of stepped pools. The second project was the very first application of the Street Edge Alternative (SEA Street) design, at 2^{nd} Avenue NW, and involved the complete reconstruction of the street and its drainage system. Both of these projects have been monitored, under the direction of Richard Horner and Stephen Burges at the University of Washington,[2] for flow in relation to precipitation to evaluate their effectiveness in controlling stormwater runoff. Flow was measured with shaft encoder floats and pressure transducers that recorded water depths behind V-notch weirs. Precipitation was recorded using tipping bucket gauges. The record extends for more than four water years beginning on October 1, 2000. Some earlier baseline data were also collected from the street preceding the SEA Street project.

Upstream and downstream monitoring has demonstrated that the Viewlands Cascade, which drains a 26-acre basin, is capable of reducing the mean influent peak flow rate by approximately 60% and total runoff volume by more than half, although little or no reduction of either peak flow rate or volume occurred in relatively large storms. There was no discharge from the end of the channel in 27% of the events monitored. It can completely infiltrate the catchment response to about 0.13 inch (3.3mm) of precipitation and 1750 ft^3 (50 m^3) of influent regardless of the season or conditions. Based on the estimates for the ditch that preceded the Viewlands Cascade project, the new channel reduces runoff discharged directly to Piper's Creek in the wet months by a factor of three relative to the old ditch.

Figure 6. Construction of swale at 110th Street cascade pilot project, Seattle, Fall 2003.

Monitoring results for the 2nd Avenue SEA Streets project indicate the prevention of discharge of all dry season flow and 99% of the wet season runoff. This project's performance has advanced since its installation, to the point that it has not discharged since December 2002, even during large rainfalls in the autumn of 2003. The preceding street discharged flow in all 35 rainfall events for which baseline data are available. An increase in infiltration and evapotranspiration is attributed to maturing vegetation. It was estimated that a conventional City of Seattle street drainage system design in the same location would have discharged almost 100 times as much runoff to Piper's Creek as the SEA Streets alternative.

Despite serving a catchment less than 10% as large as the Viewlands Cascade, the 2nd Avenue NW project retains one-quarter to one-third as much runoff volume in the wet season as Viewlands, and thus has higher efficiency on a unit area basis. However, when normalized in terms of the cost per unit catchment area served, the SEA Streets project is considerably less cost-effective than the Cascade channel.

The Viewlands Cascade and SEA Streets projects represent different strategies for controlling the quantity of urban runoff. The SEA Street is a source control strategy that can manage a large proportion of the precipitation falling on its catchment, while the Cascade is an end-of-pipe approach that can attenuate a large quantity of already flowing runoff, although not nearly as high a percentage as the source control option. These two urban stormwater management strategies can be used in concert where appropriate to increase the overall effectiveness of the total system.

The environmental benefits of the Cascade and SEA Streets projects are significant to improving urban stream quality and reducing the amount of pollution entering Puget Sound. While this work in itself does not generate pristine salmon habitat, experts, such as Dr. Derek Booth, a professor at the University of Washington, suggest that addressing hydrologic conditions is an essential element of stream restoration.[3] That is, without the installation of distributed stormwater systems, it is doubtful that the urban creeks in Seattle could ever support a sustainable, healthy population of salmon.

Cost Effectiveness

The city of Seattle is finding that in addition to providing significant environmental protection, the implementation of natural drainage systems is more cost effective to implement than traditional systems. The reduction of runoff at its source has reduced the need to build and maintain costly infrastructure, such as pipes and holding tanks. It also mitigates the pollution of local waterways, thus lowering costs to the city in

Figure 7. A cascade in full flood at Broadview Green Grid, Seattle, Washington.

the long run. In addition, the tools of natural drainage systems – plants and trees – maintain themselves and increase their benefit with time as they grow bigger and provide more surface area to slow runoff. SPU estimates that natural drainage systems cost 25% less than traditional roadside development. This cost reduction does not factor in environmental services such as increased carbon sequestration through the planting of trees, cleaner waterways, and replenished groundwater—when these benefits are considered, the actual benefit to society is likely much greater.

Public Appeal

Public support for natural drainage systems has been very enthusiastic. Neighborhood residents and community activists alike are supportive of the concept and the implementation. SPU has been working diligently to involve residents in all stages of planning and implementation. The residents are supportive of the programs because they are planting trees and public gardens along the streets, making their neighborhoods more livable and aesthetically appealing. Redesign of old streets has added sidewalks to areas where there were none. The curvilinear streets are slowing the speed of traffic, in effect creating a pedestrian-friendly environment. Many residents attribute a recent rise in property values to the installation of NDS systems along their streets; additional market data will need to be collected to prove this. Finally, many residents are proud to be associated with the NDS initiative because of the environmental benefits it is beginning to yield.

Together these benefits go beyond the initial SPU aim of improving salmon habitat; the project appears to be improving the entire ecosystem, using government funds efficiently, and enhancing the quality of life of Seattle residents. This culmination of improvements has increased the visibility of the NDS program, and has drawn to SPU's door municipal officials and stormwater engineers from far and near seeking more information.

Building on Earlier Initiatives

Utilizing the idea that biological systems can effectively retain rainwater and provide environmental and economic benefits is not new in the United States. Part of the rationale for creating the Adirondack Preserve in New York State and National Forests across the country was that these public forests would absorb rain where it fell and replenish groundwater supplies that feed major navigable rivers. Heightened awareness of the pollution-related damages caused by stormwater runoff in the mid-1980s inspired creative initiatives to mitigate such impacts. Prince George's County, Maryland in metropolitan Washington, D.C. actively sought new methods to reduce runoff into its local estuary, Chesapeake Bay, and implemented a variety of low impact development (LID) designs for stormwater control. Such LID designs included bio-swales and rain gardens. In 1998, the U.S. Environmental Protection Agency awarded Prince George's County a first place national award for the Outstanding Municipal Stormwater Program, setting it as an example for the rest of the country.

Denise Andrews and her colleagues picked up on the LID ideas then gaining currency to propose a novel approach to retrofitting city streets in northwest Seattle. Previously, LID had only been applied to small areas, such as parking lots or individual buildings, or in new suburban developments. Seattle was the first major city in America to apply these techniques to existing city streets and neighborhoods.

The number of jurisdictions interested in learning more about NDS indicates the success of the Seattle program. Since its implementation, SPU has given over 50 tours to representatives from local communities, across the United States, and around the world. Almost any local government challenged to comply with EPA stormwater management regulations could benefit from learning more about the NDS program in Seattle. The lessons are applicable both for jurisdictions that are redeveloping traditionally built infrastructure and for those permitting new subdivisions and developments.

Things to Look Out For

As SPU has moved forward in developing its initiative they have come up against challenges. Initial obstacles to implementing the low-impact development approaches came from within the city government. City traffic engineers were at first opposed to the redesigned street plans that reduced the total paved surface area. According to SPU, the redesigned streets are gradually gaining favor with this group of individuals. Emergency response professionals were also concerned that narrower streets might impair the delivery of public safety services. Once the pilot project was completed, the alternative street designs gradually gained acceptance among public safety officials, as they found that their ambulances and fire trucks could navigate the curvilinear street without exceptional difficulty.

With continued development of SEA and cascade projects some risks remain. From an engineering perspective, there are two main concerns. One is that if the infiltration of a redesigned soil bed or vegetated swale does not work properly, the result could be standing water in the neighborhoods. Recognizing that standing water provides a breeding ground for mosquitoes and other insects, the swales have been designed to drain completely within three to five days; mosquitoes require six days of standing water to breed. Another potential engineering problem is the risk that repeated infiltration might cause slope instability. To reduce this risk, the city is remaining cautious in implementing the LID techniques in steep, densely populated areas and adhering to strict engineering standards.

In an effort to encourage citizen involvement and reduce costs, SPU has enlisted homeowners to contribute to the maintenance of their street-side gardens. Initial response to this request by residents has been quite positive. However, if the gardens are not maintained there will be an increased cost to the government to manage these areas.

Inspiring Innovation

In applying for an Innovations in American Government Award, the City of Seattle demonstrated that its effort met each of the four key criteria considered by site visitors and competition judges: *novelty, significance, effectiveness, and transferability*. A fifth criteria—*the ability to endure* as an innovation—was also met. Seattle's Deputy Mayor, Tim Ceis, and SPU Director, Chuck Clarke, explained that the NDS program is likely to have a long life for several reasons. First, all reports to date indicate that it achieves its stated objectives in a cost-effective manner.[4] Second, as it is currently structured, the revenues that support the program come from SPU stormwater fees, which by law the City of Seattle cannot use for any purpose other than stormwater-related efforts. Third, the program enjoys widespread support not only from elected officials and experienced city managers, but also from local political advocates.

With this significant political and financial support behind them, Denise Andrews and her team are actively expanding the NDS program. Having successfully completed the 32-acre Broadview Green Grid, a SEA Streets project, in September 2004, they are planning another 15-block SEA, called the Pinehurst Green Grid, to be installed in Seattle's Thornton Creek watershed. In the most ambitious initiative to date, SPU is working with the Seattle Housing Authority to apply NDS methods to a 34-block high-density housing redevelopment called High Point. The redevelopment project will cover 129 acres and encompass 10 percent of the Longfellow Creek watershed. High Point is challenging SPU to achieve significant stormwater absorption while maintaining traditionally designed curbs, gutters and sidewalks.[5] Once completed, High Point should provide a significant test case for the use of LID methods in a high-density urban area. As SPU continues to evolve its NDS program, widely distributed groups of stormwater management officials, as well as citizens striving to improve local water quality conditions, are likely to notice.

For More Information

Visit the Seattle Public Utilities web site at http://www.ci.seattle.wa.us/util/About_SPU/Drainage_&_Sewer_System/Natural_Drainage_Systems/index.asp.

Endnotes

[1] Seattle Public Utilities Press Release, "Natural Drainage Systems Receive $100,000 Award: Harvard Recognizes Innovative City Program," July 28, 2004. City of Seattle: Seattle, WA. See http://www.ci.seattle.wa.us/util/About_SPU/News/News_Releases/COS_003041.asp.

[2] Horner, Richard R., Heungkook Lim, and Stephen J. Burges. "Hydrologic Monitoring of the Seattle Ultra-Urban Stormwater Management Projects: Summary for the 2000-2003 Water Years." Water Resources Series: Technical Report No. 181, Department of Civil and Environmental Engineering, University of Washington, Seattle, Washington, October 2004.

[3] Field interview of Dr. Derek Booth by James N. Levitt, February 12, 2004, Seattle, Washington.

[4] Field interview of Tim Ceis and Chuck Clark by James N. Levitt, February 12, 2004, Seattle, Washington.

[5] See "High Point Project" on the Seattle Public Utilities website: http://www.ci.seattle.wa.us/util/About_SPU/Drainage_&_Sewer_System/Natural_Drainage_Systems/High_Point_Project/index.asp, as of September 2004.

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